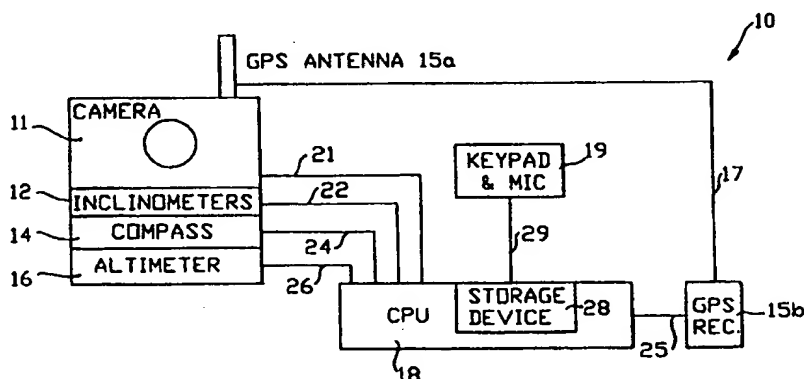




## INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

|  |  |  |  |
|--|--|--|--|
| (51) International Patent Classification <sup>6</sup> :<br><b>H04N 7/18, 9/47, 5/225, G03B 17/24,<br/>G01V 1/00, G01W 1/10, G06F 17/00,<br/>G06G 7/48</b>  |  | <b>A1</b>  | (11) International Publication Number:<br><b>WO 99/18732</b>     |
|  |  |  | (43) International Publication Date:<br>15 April 1999 (15.04.99) |
| (21) International Application Number: PCT/US98/20809<br>(22) International Filing Date: 5 October 1998 (05.10.98)<br>(30) Priority Data:<br>08/944,887                      6 October 1997 (06.10.97)                      US<br>(71)(72) Applicant and Inventor: CIAMPA, John, A. [US/US];<br>275 Alexander Street, Rochester, NY 14607 (US).<br>(74) Agent: FITZGERALD, Thomas, R.; Jaeckle Fleischmann &<br>Mugel, LLP, 39 State Street, Rochester, NY 14614-1310<br>(US). |  | (81) Designated States: AL, AM, AT, AU, AZ, BA, BB, BG, BR,<br>BY, CA, CH, CN, CU, CZ, DE, DK, EE, ES, FI, GB, GE,<br>GH, GM, HR, HU, ID, IL, IS, JP, KE, KG, KP, KR, KZ,<br>LC, LK, LR, LS, LT, LU, LV, MD, MG, MK, MN, MW,<br>MX, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ,<br>TM, TR, TT, UA, UG, UZ, VN, YU, ZW, ARIPO patent<br>(GH, GM, KE, LS, MW, SD, SZ, UG, ZW), Eurasian patent<br>(AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent<br>(AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT,<br>LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI,<br>CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).<br><br>Published<br>With international search report. |  |

(54) Title: DIGITAL-IMAGE MAPPING



## (57) Abstract

In accordance with the present invention, there is provided an image capture and georeferencing unit. The unit comprises in combination, a portable camera (11) with a GPS antenna and receiver (15b) that captures global coordinates, a compass (14) for determining the direction and an inclinometer (12) for the photographic angle. The camera and other instruments feed image and shot data to a CPU (18), where the shot data is analyzed, mathematically interpolated and reconciled with known constants. The image and shot data are stored in memory (28). The "shot data" analyzed by the computer includes camera parameters such as camera: location, latitude, longitude and altitude, time, bearing, depression angle/pitch or azimuth, roll and yaw. The portable camera and data-gathering instruments move together and, therefore, function as a single unit that provides precise, accurate data and digitized photographic image information, despite topographical changes and/or altitude variations of the camera. Exact digital representations with precise coordinates are instantly available for precise reconnaissance purposes. The photographic shot data is mathematically adjusted (trigonometrically) to coordinate the points on the ground plane with the points in the image plane in order to produce an automatically computationally georeferenced digital image. Elevation data may be used to corroborate or enhance the accuracy of the trigonometric interpolations.

**FOR THE PURPOSES OF INFORMATION ONLY**

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

|    |                          |    |  |    |  |    |                          |
|----|--------------------------|----|--|----|--|----|--------------------------|
| AL | Albania                  | ES | Spain                                    | LS | Lesotho                                      | SI | Slovenia                 |
| AM | Armenia                  | FI | Finland                                  | LT | Lithuania                                    | SK | Slovakia                 |
| AT | Austria                  | FR | France                                   | LU | Luxembourg                                   | SN | Senegal                  |
| AU | Australia                | GA | Gabon                                    | LV | Latvia                                       | SZ | Swaziland                |
| AZ | Azerbaijan               | GB | United Kingdom                           | MC | Monaco                                       | TD | Chad                     |
| BA | Bosnia and Herzegovina   | GE | Georgia                                  | MD | Republic of Moldova                          | TG | Togo                     |
| BB | Barbados                 | GH | Ghana                                    | MG | Madagascar                                   | TJ | Tajikistan               |
| BE | Belgium                  | GN | Guinea                                   | MK | The former Yugoslav<br>Republic of Macedonia | TM | Turkmenistan             |
| BF | Burkina Faso             | GR | Greece                                   |    |  | TR | Turkey                   |
| BG | Bulgaria                 | HU | Hungary                                  | ML | Mali   | TT | Trinidad and Tobago      |
| BJ | Benin                    | IE | Ireland                                  | MN | Mongolia                                     | UA | Ukraine                  |
| BR | Brazil                   | IL | Israel                                   | MR | Mauritania                                   | UG | Uganda                   |
| BY | Belarus                  | IS | Iceland                                  | MW | Malawi                                       | US | United States of America |
| CA | Canada                   | IT | Italy                                    | MX | Mexico                                       | UZ | Uzbekistan               |
| CF | Central African Republic | JP | Japan                                    | NE | Niger  | VN | Viet Nam                 |
| CG | Congo                    | KE | Kenya                                    | NL | Netherlands                                  | YU | Yugoslavia               |
| CH | Switzerland              | KG | Kyrgyzstan                               | NO | Norway                                       | ZW | Zimbabwe                 |
| CI | Côte d'Ivoire            | KP | Democratic People's<br>Republic of Korea | NZ | New Zealand                                  |    |                          |
| CM | Cameroon                 |    | Republic of Korea                        | PL | Poland                                       |    |                          |
| CN | China                    | KR | Republic of Korea                        | PT | Portugal                                     |    |                          |
| CU | Cuba                     | KZ | Kazakstan                                | RO | Romania                                      |    |                          |
| CZ | Czech Republic           | LC | Saint Lucia                              | RU | Russian Federation                           |    |                          |
| DE | Germany                  | LI | Liechtenstein                            | SD | Sudan  |    |                          |
| DK | Denmark                  | LK | Sri Lanka                                | SE | Sweden                                       |    |                          |
| EE | Estonia                  | LR | Liberia                                  | SG | Singapore                                    |    |                          |

## DIGITAL-IMAGE MAPPING

### FIELD OF THE INVENTION

The present invention pertains to the capture and  
5 automatic georeferencing of a camera and/or images captured by  
the camera by utilizing a portable camera and data unit and, more  
particularly, to a system and method of obtaining precisely  
located, oblique, digitized land images, taking into account  
diverse topography and varying camera angles, including changes  
10 in heading, roll and yaw.

### BACKGROUND OF THE INVENTION

Aerial photography of land images for reconnaissance  
purposes is well known, as illustrated in United States Patent  
No. 5,247,356 (issued to John A. Ciampa on September 21, 1993),  
15 entitled METHOD AND APPARATUS FOR MAPPING AND MEASURING LAND.  
This patent teaches that coordinates of a land location can be  
calculated and combined with photographic information about the  
terrain. The global position and the elevation information are  
converted into digitized form, along with the image information  
20 and then stored in computer memory.

One of the problems of such aerial-photography  
methodology is that photographs must be taken over landscapes of  
relatively flat terrain, while a plane's altitude is generally  
parallel with the landscape, or at aircraft altitudes where  
25 topographical variations are generally minimized in the angular  
calculations. The inability of the prior art of aerial  
photographic systems to coordinate image information with  
collateral measurements has often required the use of expensive

flight platforms, preordained flight paths and orthogonal camera angles.

In order to obtain exact geographic coordinates of any land image, it is no longer necessary to stabilize the camera, flight path and elevation, as previously calculated in the  
5 aforementioned patent. Due to additional data and calculations, the camera may now be freed up, regardless of topographical changes and changes of camera angles with respect to this changing topography.

10 The present invention combines into a single unit a portable camera with a data unit containing a Global Position Satellite (GPS) antenna/receiver, including but not limited to differential GPS or other type GPS system, a compass and inclinometer. The data unit provides camera coordinates and  
15 triaxial angle data, which are combined with the digital representations of the photographic image. Trigonometric formulas correlate to the image pixel and corresponding ground coordinates. An iterative algorithm, as is well known in fuzzy logic and optimization routines, is used to compensate for the  
20 changes and variations in the landscape topography. This is accomplished by using known Digital Elevation Models (DEM) that are furnished by the United States Geophysical Survey (USGS) or other digital terrain models captured as a result of laser signals. In addition the system's mathematical algorithms take  
25 account of the differences in measurements of known objects such as cars and distribute these differences to fixed variables which has the effect of raising, lowering, tilting or reshaping a virtual ground plane that compensates for differences caused by elevation. The particular camera to be utilized with this  
30 invention may be an analog, digital video or still digital

camera. The camera may be carried by an operator who is on foot or in a land, sea or air craft.

The inclinometer, the GPS antenna/receiver and a compass are affixed to the camera so that they move together as a unit. The inclinometer detect changes in the depression angle and the roll angles of the camera. The photographic data is attached to the image file and is transferred to a small microprocessor (CPU), where the storage device can be a PCMCIA memory card. The microprocessor processes and links the shot data from the instruments with a digital image file. All of the data regarding depression angle, global position, heading (or bearing) and image are interpolated and combined with the shot time. This digitized image and other information are then stored in a spatially managed image file mosaic software, whereby images can be retrieved based on their map location or from a gallery or "contact sheet" of digital miniature thumbnails.

The method of the invention comprises the following steps. The image is first digitally captured by a "digital" camera or other digitizing device, along with the aforementioned shot data. "Shot data" is then analyzed by the computer, including location (i.e., latitude, longitude and altitude); camera bearing or heading (the compass direction in which the lens is pointing); the camera depression angle or azimuth; and the camera roll (i.e., the yaw of the camera, with respect to its horizontal axis). The shot data is then mathematically adjusted (trigonometrically) to coordinate the points on the ground plane with the points in the image plane, so as to produce an automatically computationally georeferenced digital image. Elevation data may be used to corroborate or enhance the accuracy of the trigonometric interpolation. The result of all of this

processing provides an image, or a portion thereof, from which can be obtained geographic coordinates of any point on the ground and/or ground measurements taken between any two points in the image. This "georeferencing" of each image also determines its  
5 placement in a series of adjacent images, so that each image can be depicted as a "tile" within a "mosaic" of tiled images. Each image, in addition to its georeference, is processed so as to contain a discrete sequential identifier, the date and the time. Many images of the same landscape may be taken by using different  
10 angles and camera positions, each of which is accessible by means of a graphical user interface. Trigonometric processing also takes into account fixed variables, such as lens focal length, the size of the image plane, the number of pixels in the X-Y axes (horizontal and vertical planes) and the size of the pixels.

15 It is the object of the present invention to provide an improved oblique aerial-photography system so that any person without special "photo-interpreting" skills may conduct electronic field studies of land and building, as well as ground-based visual inventories.

20 It is another object of this invention to provide a portable photography system that combines into a single operational unit a photographic camera with a GPS antenna/receiver that captures global coordinates, a compass for determining camera direction and inclinometer for calculating the  
25 photographic angle.

It is a further object of this invention to provide a digital photographic imaging system that "georeferences" each geographical image, so that each image, or part thereof, can be depicted as a "tile" within a "mosaic" of tiled images.

## SUMMARY OF THE INVENTION

In accordance with the present invention, there is provided an image capture and georeferencing unit. The unit comprises in combination, a portable camera with a Global Position Satellite (GPS) antenna/receiver that captures global coordinates, a compass for determining the direction and an inclinometer for calculating the photographic angle. The camera and other instruments feed image and shot data to a CPU, where the shot data is analyzed, mathematically interpolated and reconciled with known constants. The image and shot data are then stored in memory. The "shot data" analyzed by the computer includes camera location (i.e., latitude, longitude and altitude), time, camera bearing (the compass direction in which the lens is pointing), the camera depression or azimuth, and camera roll (i.e., the yaw of the camera with respect to its horizontal axis). The portable camera and data-gathering instruments move together and, therefore, function as a single unit that provides precise, accurate data and digitized photographic image information, despite topographical changes and/or altitude variations of the camera. They also provide precise data on the GPS location of the camera and its altitude with respect to the ground. Exact digital representations with precise coordinates are instantly available for precise reconnaissance purposes. The photographic shot data is mathematically adjusted (trigonometrically) to coordinate the points on the ground plane with the points in the image plane in order to produce an automatically computationally georeferenced digital image. Elevation data may be used to corroborate or enhance the accuracy of the trigonometric interpolations.

The result of all of this processing provides an image,

or a portion thereof, from which can be obtained geographic coordinates of any point on the ground and/or measurements on the ground taken between any two points in the image. The "georeferencing" of each image also determines its placement in a series of adjacent images, so that each image can be depicted as a "tile" within a "mosaic" of tiled images. Each image, in addition to its georeference, is processed so as to contain a discrete sequential identifier, the date and the time. Many images of the same landscape may be taken by using different angles and camera positions, each of which is accessible by means of a graphical user interface. Processing adjusts the shot data to compensate for fixed camera data, such as the lens focal length, the size of the image plane, the number of pixels in the X-Y axes (horizontal and vertical planes) and the size of the pixels.

#### BRIEF DESCRIPTION OF THE DRAWINGS

A complete understanding of the present invention may be obtained by reference to the accompanying drawings, when considered in conjunction with the subsequent detailed description, in which:

FIGURE 1 illustrates a schematic, block diagram of the camera and instruments of this invention;

FIGURE 2 depicts a flow diagram of the processing method used in the system shown in FIGURE 1, in which an image is captured, digitized and combined with shot data and other georeferencing information, and thereafter stored for future use;

FIGURE 3 shows a flow diagram of the image file management software of the inventive system depicted in FIGURE

1; and

FIGURES 4 A-C illustrate the inventive technique used to mathematically calculate the georeference at each pixel of the image; and

5           FIGURES 5 A-B illustrate a schematic view of the inventive technique used to mathematically reconcile the shot data with Digital Elevation Models and/or other known "ground truth".

#### DESCRIPTION OF THE PREFERRED EMBODIMENT

10           Generally speaking, the invention features an imaging system, including a novel combination of a portable camera, GPS receiver, bearing compass and inclinometer(s). All of the components move and function as a single unit, so that, despite changes in the depression and the roll angles of the camera, each  
15   digital image is captured, along with shot data, which becomes automatically, computationally georeferenced.

Now referring to FIGURE 1, an imaging system 10 of this invention is illustrated. The system combines a camera 11 with an inclinometer 12, a compass 14, an optional altimeter 16 and  
20   a Global Position Satellite (GPS) antenna/receiver, 15a and 15b, respectively. The particular camera 11 that can be utilized with this invention may be a databack film camera that is capable of affixing shot time and subsequent digitization. The camera 11 can also be an analog, a digital video or a still digital camera.  
25   The camera 11, inclinometer 12, compass 14, optional altimeter 16 and GPS receiver 15b are each individually connected to a CPU processor 18 containing a fixed or removable memory 28 (such as a PCMCIA card) via respective lines 21, 22, 24, 26 and 25. The

GPS antenna 15a is connected to the GPS receiver 15b via line 17. Also connected to the CPU processor 18 are an optional key-pad-and microphone 19 via line 29. The key-pad-and-microphone 19 can be used to enter comments or additional information with respect to the photographed site. Where altitude provided by the GPS is adequate, the altimeter 16 may be dispensed with. Where comments are impractical, the key-pad-and-microphone 19 may also be dispensed with.

The invention reflects the discovery that in addition to camera location, it is necessary to factor into the calculations the changes in the elevation of the depicted land, the depression and the bearing of the camera, with respect to this encompassed land. The compass 14 provides camera heading or bearing information; the GPS antenna/receiver 15a and 15b provide the camera position information (latitude, longitude and altitude); the inclinometers 12 provide the depression and roll angles; and the optional altimeter laser or other 16 provides additional altitude information. As an alternative to or in addition to instrumental measurements of land, the system may computationally deduce elevations within the image by assessing deficiencies in measurements of known objects such as cars. These variables are combined with the digital image, plane measurements, focal length, and pixel data to give a georeferenced image down to the pixel level.

The instrument's shot data are recorded and used to coordinate the points on the ground plane with the points in the image plane in order to produce a georeference for each pixel. DEM data are used to corroborate or enhance the accuracy of the trigonometric interpolations. The result of all of this processing provides an image, or a portion thereof, from which

can be obtained geographic coordinates of any point on the ground and/or measurements on the ground taken between any two points in the image. The "georeferencing" of each image also determines its placement in a series of adjacent images, so that each image  
5 can be depicted as a "tile" within a "mosaic" of tiled images. Each image, in addition to its georeference, is processed so as to contain a discrete sequential identifier, the date and the time. Many images of the same landscape may be taken by using different angles and camera positions, each of which is  
10 accessible by means of a graphical user interface. Processing adjusts the shot data to compensate for the lens focal length, the size of the image plane, the number of pixels in the X-Y axes (horizontal and vertical plans) and the size of the pixels.

The GPS antenna/receiver 15a and 15b can be obtained  
15 from, among others, Trimble Navigation Systems of Sunnyvale, California. A fluxgate compass 14 and inclinometers 12 are available from, among others, KVH Industries, Inc., of Middletown, Rhode Island.

In processing the information, the CPU 18 accesses  
20 Digital Elevation Model (DEM) data from a database in order to adjust the image data for topographical variations. The position variables (camera X, Y and Z coordinates) are obtained from the Global Position Satellite (GPS) receiver. The pointing variables (camera heading or bearing) are obtained from the compass 14, and  
25 the depression and the roll information are obtained from the inclinometers 12.

The processing assumes a simple, pin-hole camera model. The ground position of the photographed image can be defined by simple triangular, trigonometric processing of the depression

angle  $\phi_d$ , the size of the image plane and the focal length (FL) of the camera as shown in FIGURE 4A. A pixel location ( $P_x$ ,  $P_y$ ) of a particular point selected on a displayed image can be processed for a particular depression angle by calculating the inverse  
 5 tangent of the angle as shown in FIGURE 4B.

Referring to FIGURE 4C, assuming a northerly direction, the angle  $\phi_d$  (depression angle) is offset by the arctangent (film height  $[y]$  \* (row containing focal axis  $[F_y]$  - row of selected pixel  $[P_y]$ )/2 \* image plane height  $[Z]$  \* focal length  
 10  $[FL]$ ) resulting in angle  $\phi_p$ . The angle  $\phi_p$  is subtracted from the recorded depression angle  $\phi_p$  and denoted as  $\rho_v$  relative to the point on the ground immediately below the camera, with camera altitude above the ground "Z" (height). The northerly distance to the selected point  $[P_x, P_y]$  is  $Z * \sin (\pi/2 - \rho_v)$ . The east-  
 15 west distance is calculated from the (column of selected pixel  $[P_x]$  - focal axis column  $[F_x]/2$ ) \* film width  $[x]$  / image plane width  $[x_1]$ .

$$\text{east-west distance} = \text{Camera } Z * \cos \phi/2 * \text{focal length} * \sin \rho_v$$

When the direction is other than north, a simple  
 20 rotation is made on the point to establish the ground location. The true location is then obtained by translating the ground location of the camera into its recorded position.

Ground location for terrain "T" that is not flat is adjusted by using DEM data and an iterative algorithm, well known  
 25 in the art of optimization routines. The processor 18 uses the algorithm and the point  $[g_1]$  assumed for a flat terrain as shown in FIGURE 5A. The processor accesses the DEM data for that point and obtains the elevation  $[g_2]$  as shown in FIGURE 5B. The process is complete if the elevation at that camera location is

the same as that of the selected point. Otherwise, the camera elevation is modified to account for the difference in the ground elevation of the selected point. The revised value is then used to estimate the ground location ( $G_3$ ). The iterative algorithm  
5 continues to revise the estimate until it converges to within acceptable limits. The algorithm is modified to adjust for roll of the camera by transforming pixel coordinates to a new set of coordinates. The transformation is a simple rotation about focal axis "F" by well-known mathematical methods.

10 
$$T\mu = [\cos \mu \sin \mu] - \sin \mu \cos \mu$$

The data points provided by the DEM are sampled along the ground every 30 meters in an orthogonal grid bounded by  $g_2$  and  $g_1$ , as shown. Intermediate points are obtained by interpolation, such as by using bilinear interpolation or bicubic  
15 splines.

The position of the camera and the pointing angles are subject to a small degree of error and, therefore, may be reconciled with measured ground truth other than DEM data. This is accomplished by locating or measuring discrete objects in  
20 several images and then modifying the collected data so as to obtain more accurate estimates.

Referring to FIGURE 2, a flow chart 100 is illustrated for the image-and-data-capture process of this invention. An image is captured by camera 12, step 101; the image information  
25 is converted to digital form, step 102. The camera altitude, ground location, tilt, depression angle and heading (bearing) are then obtained, as shown in step 103. The information from steps 102 and 103 is then combined, step 104. The data is then adjusted according to focal length, pixel size, pixel location

and focal axis, as previously explained with reference to FIGURE 4, step 105. The result of all of the processing provides an image, or a portion thereof, from which can be obtained geographic coordinates on the ground and/or ground measurements taken between any two image points. The "georeferencing" of each image determines its placement in a series of adjacent images, so that each image can be depicted as a "tile" within a "mosaic" of tiles images, step 106. The DEM data is then used to adjust the image data for variations in the terrain, step 107. The image data is then compressed for storage purposes, step 108.

Referring to FIGURE 3, a flow chart 200 illustrates in more detail the DEM adjustment process for the data obtained in FIGURE 2. A tile from the mosaic is obtained, steps 201 and 202. In conjunction with the selection, an associated DEM elevation file is accessed, step 203. The accessed data is then combined and the digitized data decompressed, step 204. The image and adjoining images are then displayed, step 206. Certain features of the images are selected, step 207, and the horizontal or vertical measurements are selected for review, step 208. Different images are reviewed, step 210, and the end points are measured, step 209. The ground points are then estimated, step 211, and compared with the DEM data, step 212. If the elevation estimate is different, the elevation is revised, step 214, and entered via line 215. A new estimate is made via return loop 205, and the re-entering of step 211. After a few iterations, the decision is made, step 212, to report distance between points, step 217 via line 216. When the estimate is found accurate, the actual distance between the selected ground points is made, step 217. The process is then repeated via return loop 220, in order to obtain the distance values for other selected

points and tiles.

The invention has been described in detail with particular reference to certain preferred embodiments thereof, but it will be understood that variations and modifications can  
5 be effected within the spirit and scope of the invention.

What is claimed is:

1. An image georeferencing system, comprising:

a portable, data-capturing device affixed to a camera, with said camera providing an image, said portable, data-capturing device and said camera being carried by hand or upon an aerial surveillance vehicle or other craft, said portable, data-capturing device providing data for computationally generating a georeference, and being independently operative of any aeronautical instruments, said portable, data-capturing device further including at least one inclinometer for determining depression angle, a means for determining heading or bearing of said data-capturing device and a global position satellite antenna/receiver for obtaining georeferencing information, said at least one inclinometer and said global position satellite antenna/receiver being movable as a single unit; and

a processor operatively connected to said portable, data-capturing device and said camera, said processor comprising data storage means, including digital elevation information and a program for modifying image and georeferencing information with respect to variations in terrain and changes in heading, roll and yaw of said data-capturing device, said processor computationally generating a georeference of any object within said image, in which said object can be located and measured therewithin.

2. The imaging georeferencing system in accordance with claim 1, further comprising an altimeter connected to said processor for determining additional altitude data of said portable, data-capturing device.

3. The imaging georeferencing system in accordance with claim 1, further comprising a key pad connected to said processor for entering pilot information into said processor.

4. The imaging georeferencing system in accordance with claim 1, further comprising a microphone connected to said processor for entering comments into said processor.

5. An image georeferencing system, comprising:

a camera for providing an image in combination with a georeferencing, data-capturing device and inclinometer, said combination carried by hand or upon an aerial surveillance vehicle or other craft, said georeferencing, data-capturing device capturing data for computationally generating a georeference of any object within said image; and

a processor connected to said camera and georeferencing, data-capturing device combination, said processor comprising data storage means, including digital elevation information and a program for modifying image and georeferencing information with respect to variations in terrain and changes in heading, roll and yaw of said data-capturing device and processing said captured data for computing a georeference of any object within said image.

6. The image georeferencing system in accordance with claim 5, wherein said camera and georeferencing, data-capturing device combination comprises at least one inclinometer for determining depression angle, a means for determining heading of said image and a global position satellite antenna/receiver for obtaining georeferencing information with respect to said image, said at least one inclinometer and said global position satellite

antenna/receiver being movable as a single unit, with each being connected to said processor.

7. The image georeferencing system in accordance with claim 6, further comprising an altimeter connected to said processor for determining additional altitude data.

8. The image georeferencing system in accordance with claim 5, further comprising a key pad connected to said processor for entering comments into said processor.

9. The image georeferencing system in accordance with claim 5, further comprising a microphone connected to said processor for entering comments into said processor.

10. A method of computationally georeferencing images, comprising the steps of:

a) capturing an image of terrain to provide digitized image information;

b) combining said digitized image information with shot data from instrumental data and camera data;

c) analyzing said combined digitized image and said shot data;

d) obtaining information with respect to image location data, including at least one of a group of location data including variations in camera latitude, longitude, altitude, camera bearing, camera depression angle, roll and yaw; and

e) adjusting information obtained in step (b) and utilizing information obtained in step (d) to coordinate points on a ground plane with points in an image plane to produce

a georeferenced digital image of the terrain.

11. The method in accordance with claim 10, further comprising the step of:

5 f) utilizing digital elevation model data to enhance accuracy of image and georeferencing information obtained in step (b).

12. The method in accordance with claim 10, further comprising the step of:

10 f) processing said information obtained in step (b) to provide an image, or a portion thereof, that can be spatially located by using geographic coordinates and/or measurements taken between any two points.

13. The method in accordance with claim 10, further comprising the step of:

15 f) depicting combined image information and georeferencing information as a "tile" within a "mosaic" of tiled images, with each image, in addition to its respective georeference, being processed so as to contain a discrete sequential identifier, date and time.

20 14. The method in accordance with claim 10, further comprising the step of:

f) capturing a multiplicity of images of the same terrain in accordance with step (a) by using different angles and capture positions to provide different points of view of the same scene, each of which being accessible by means of a graphical user interface.

25

15. The method in accordance with claim 10, further comprising the steps of:

f) obtaining information with respect to lens focal length, size of image plane, number of pixels in horizontal and vertical planes, and size of pixels; and

g) processing said image information in step (a) with respect to said information obtained in step (f) to adjust said image information.

16. A method of aerial surveillance of terrain, comprising the steps of:

f) aerially capturing an image of terrain to provide image information;

g) combining said image information with shot data as georeferencing variables;

h) analyzing said combined image and said georeferencing variables;

i) obtaining information with respect to image location data, including at least one of a group of location data including variations in camera latitude, longitude, altitude, camera bearing, camera depression angle, roll and yaw; and

j) adjusting information obtained in step (b) and utilizing information obtained in step (d) to coordinate points on a ground plane with points in an image plane to produce an exact image of the terrain.

17. The method in accordance with claim 16, further comprising the step of:

f) utilizing digital elevation model data to enhance accuracy of image and georeferencing information obtained in step (b).

18. The method in accordance with claim 16, further  
5 comprising the step of:

f) processing said information obtained in step (b) to provide an image, or a portion thereof, that can be spatially located by using geographic coordinates and/or make known geographic coordinates of the ground at any point depicted  
10 in the image and/or ground measurements taken between any two points of the image.

19. The method in accordance with claim 16, further comprising the step of:

f) depicting combined image information and  
15 georeferencing information as a "tile" within a "mosaic" of tiled images, with each image, in addition to its respective georeference, being processed so as to contain a discrete sequential identifier, date and time.

20. The method in accordance with claim 16, further  
20 comprising the step of:

f) taking a multiplicity of images of the terrain in accordance with step (a) by using different angles and capture positions to provide multiple views, accessible by means of a window-like, graphical user interface.

25 21. The method in accordance with claim 16, further comprising the steps of:

f) obtaining information with respect to lens focal length, size of image plane, number of pixels in horizontal and vertical planes, and size of pixels; and

g) processing said image information obtained in step (a) with respect to said information obtained in step (f) to adjust said image information.

22. An image georeferencing system comprising

a camera for providing an image in combination with a georeferencing, data-capturing device, said combination carried by hand or upon an aerial surveillance vehicle or other craft, said georeferencing, data-capturing device capturing data for computationally generating and recording a georeference of the camera for each captured image; and further comprising a device selected from the group consisting of an inclinometer, means for determining heading or bearing of the camera.

23. The image georeferencing system of claim 22 further comprising a processor connected to said camera and georeferencing, data-capturing device combination, said processor comprising data storage means, including digital elevation information and a program for modifying image and georeferencing information with respect to variations in terrain and changes in heading, roll and yaw of said data-capturing device and processing said captured data for computing a georeference of any object within said image.

24. The image georeferencing system of claim 23 wherein said camera further comprising means for recording the depression and roll angle of the camera for each image captured by the camera.

25. The image georeferencing system of claim 23 wherein said camera further comprising means for recording the altitude of the camera for each image captured by the camera.

26. The image georeferencing system of claim 23  
5 wherein said georeference data is obtained by a global position system antenna and receiver connected to the processing unit.

27. The image georeferencing system of claim 26 wherein said processing unit is within said camera.

28. The image georeferencing system of claim 24  
10 wherein said angle means is an inclinometer connected to the processing unit.

29. The image georeferencing system of claim 25 wherein said altitude means is an altimeter connected to the processing unit.

15 30. A digital mapping system, comprising:

a portable data-capturing device affixed to a camera, said camera providing an image, said portable data-capturing device and said camera being carried by hand or upon an aerial surveillance vehicle or other craft for providing a  
20 pixel-based image, said portable data-capturing device providing data for computationally generating a georeference for each pixel of said pixel-based image, said data-capturing device being independently operative of any aeronautical instruments, said portable data-capturing device further including at least one  
25 inclinometer for determining declination angel, a means for determining heading or bearing of said image-capturing device and a global position satellite antenna/receiver for obtaining georeferencing information, said at least one inclinometer and

said global position satellite antenna/receiver being movable as a single unit; and

a processor operatively connected to said portable data-capturing device and said camera, said processor comprising  
5 data storage means, including digital elevation information and a program for modifying image and georeferencing information with respect to variations in terrain and changes in heading, roll and yaw of said data-capturing device, said processor computationally  
10 generating a georeference of each pixel and any object within said image, wherein said object can be located and measured within said image.

31. The imaging georeferencing system in accordance with claim 30, further comprising a key pad connected to said processor for entering pilot information into said processor.

15 32. The imaging georeferencing system in accordance with claim 30, further comprising a microphone connected to said processor for entering comments into said processor.

33. An image georeferencing system in accordance with claim 30, further comprising:

20 a camera for providing an image in combination with a georeferencing, data-capturing device and inclinometer, said combination carried by hand or upon an aerial surveillance vehicle or other craft, said georeferencing, data-capturing device capturing data for computationally generating a  
25 georeference of any object within said image; and

a processor connected to said camera and georeferencing, data-capturing device combination, said processor comprising data storage means, including digital elevation

information and a program for modifying image and georeferencing information with respect to variations in terrain and changes in heading, roll and yaw of said data-capturing device and processing said captured data for computing a georeference of any  
5 object within said image.

34. A digital mapping system, comprising:

a camera for providing a pixel-based image in combination with a georeferencing data-capturing device, said combination carried by hand or upon an aerial surveillance  
10 vehicle or other craft, said georeferencing data-capturing device capturing data for computationally generating a georeference of each pixel and any object within said image; and

a processor connected to said camera and georeferencing data-capturing device combination, said processor  
15 comprising data storage means, including digital elevation information and a program for modifying image and georeferencing information with respect to variations in terrain and changes in heading, roll and yaw of said image-capturing device, and processing said captured data for computing a georeference of  
20 each pixel and any object within said image.

35. The image georeferencing system in accordance with claim 34, wherein said camera and georeferencing, data-capturing device combination comprises at least one inclinometer for determining depression angle, a means for determining heading of  
25 said image and a global position satellite antenna/receiver for obtaining georeferencing information with respect to said image, said at least one inclinometer and said global position satellite antenna/receiver being movable as a single unit, with each being connected to said processor.

36. The image georeferencing system in accordance with claim 35, further comprising an altimeter connected to said processor for determining additional altitude data.

37. The image georeferencing system in accordance with claim 34, further comprising a key pad connected to said processor for entering comments into said processor.

38. The image georeferencing system in accordance with claim 34, further comprising a microphone connected to said processor for entering comments into said processor.

39. A method of digitally mapping terrain, comprising the steps of:

a) capturing a pixel-based image of terrain to provide digitized image information;

b) capturing georeferencing information;

c) combining said digitized image information with said captured georeferencing information; and

d) processing said combined digitized image information and said captured georeferencing information in order to generate a georeference of each pixel and any object within said image of said terrain, whereby said object can be located within said image of terrain.

40. The method in accordance with claim 39, further comprising the step of:

f) utilizing digital elevation model data to enhance accuracy of image and georeferencing information obtained in step (b).

43 in accordance with claim 39, further comprising t

ssing said information obtained in step (b) to prove, or a portion thereof, that can be spatially lusing geographic coordinates and/or measurements en any two points.

method in accordance with claim 39, further comprstep of:

10 icting combined image information and georeferencing on as a "tile" within a "mosaic" of tiled images, withage, in addition to its respective georeference, ocessed so as to contain a discrete sequential ideate and time.

15 method in accordance with claim 39, further compristep of:

uring a multiplicity of images of the same terrain in accoith step (a) by using different angles and capture positiovide different points of view of the same scene, each of eing accessible by means of a graphical user interface.

4 method in accordance with claim 39, further comprisi steps of:

25 faining information with respect to lens focal length, sizimage plane, number of pixels in horizontal and vertical plannd size of pixels; and

g)cessing said image information in step (a)

with respect to said information obtained in , adjust  
said image information.

45. A method of aerial surveillance of terrain,  
comprising the steps of:

- 5           a) aerially capturing a[n] pixel image of  
terrain to provide image information;
- b) combining said image on with  
georeferencing information; and
- 10           c) processing said combined and said  
georeferencing information, in order to generate  
of each pixel and any object within said terrain,  
whereby said object can be located within said terrain.

46. The method in accordance with 45, further  
comprising the step of:

- 15           f) utilizing digital elevation data to  
enhance accuracy of image and georeferencing  
information obtained  
in step (b).

47. The method in accordance with 45, further  
comprising the step of:

- 20           f) processing said information obtained in step  
(b) to provide an image, or a portion of, that can be  
spatially located by using geographic coordinates and/or make  
known geographic coordinates of the ground point depicted  
in the image and/or ground measurements between any two  
25 points of the image.

48. The method in accordance with claim 45, further

comprising the step of:

f) depicting combined image information and georeferencing information as a "tile" within a "mosaic" of tiled images, with each image, in addition to its respective  
5 georeference, being processed so as to contain a discrete sequential identifier, date and time.

49. The method in accordance with claim 45, further comprising the step of:

f) taking a multiplicity of images of the  
10 terrain in accordance with step (a) by using different angles and capture positions to provide multiple views, accessible by means of a window-like, graphical user interface.

50. The method in accordance with claim 45, further comprising the steps of:

15 f) obtaining information with respect to lens focal length, size of image plane, number of pixels in horizontal and vertical planes, and size of pixels; and

g) processing said image information obtained in step (a) with respect to said information obtained in step (f)  
20 to adjust said image information.

1/7

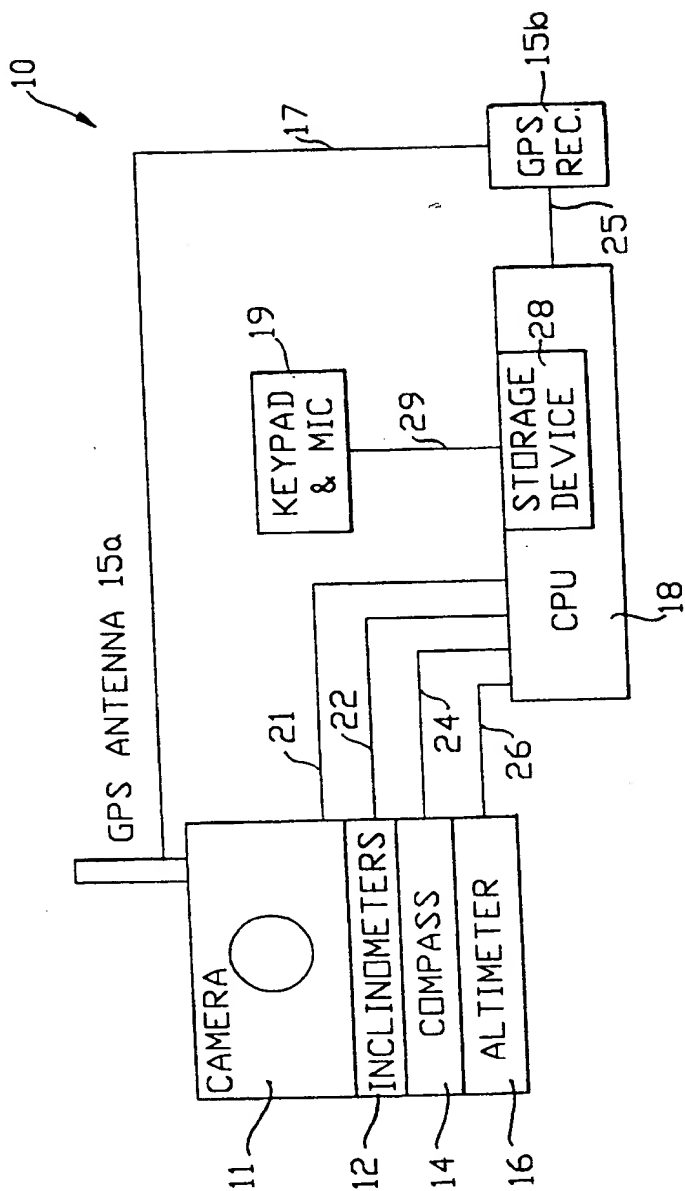
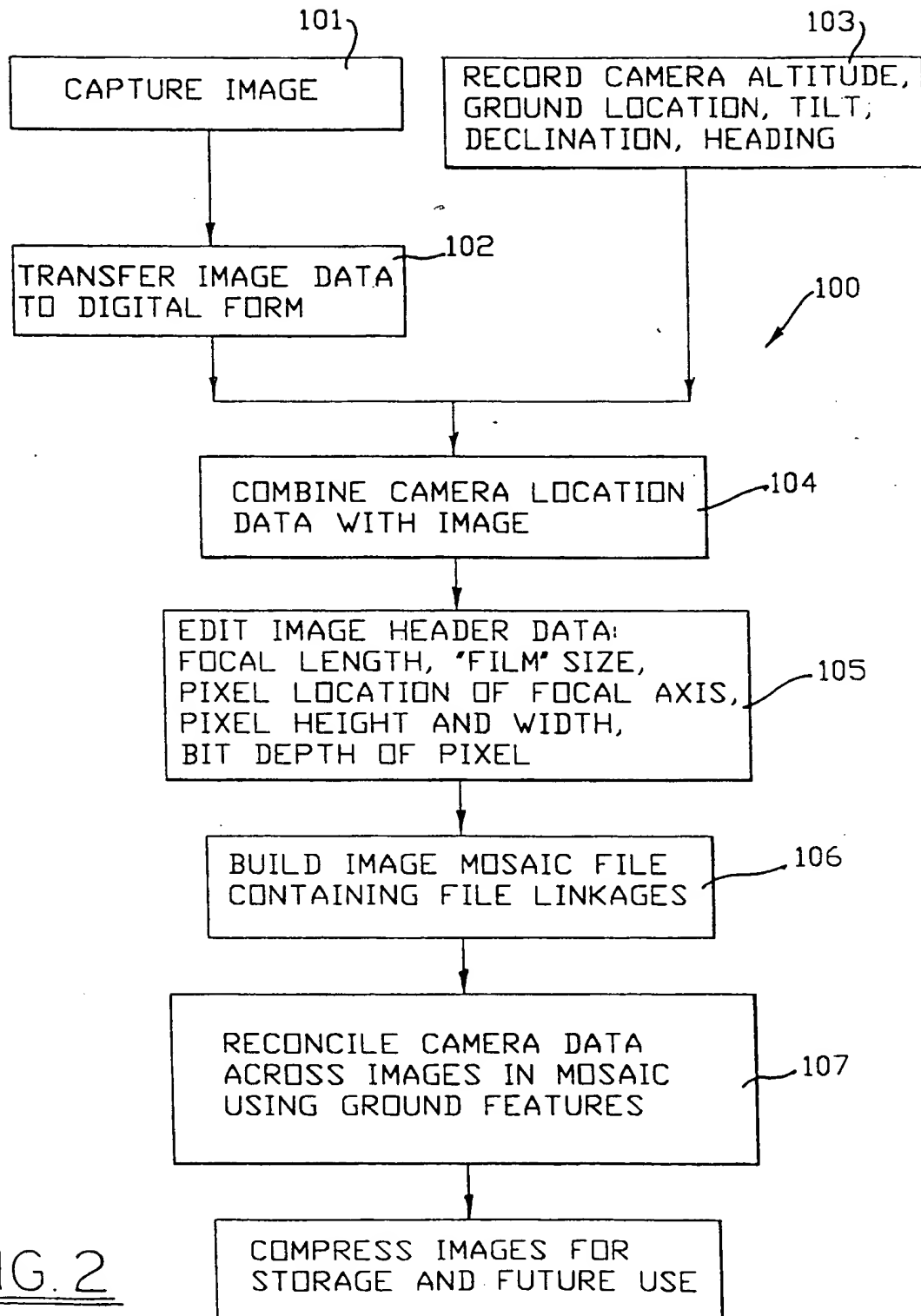
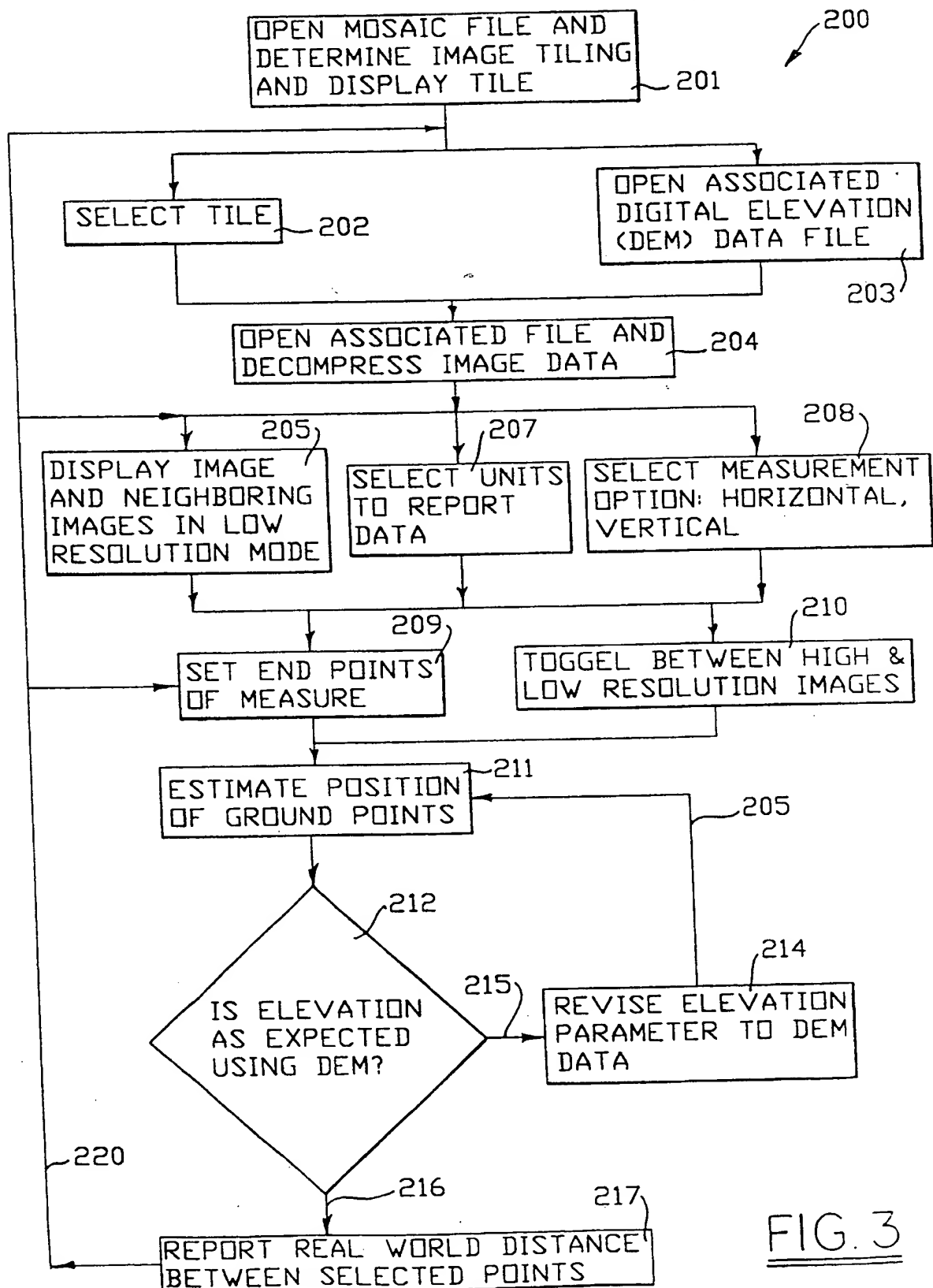


FIG. 1

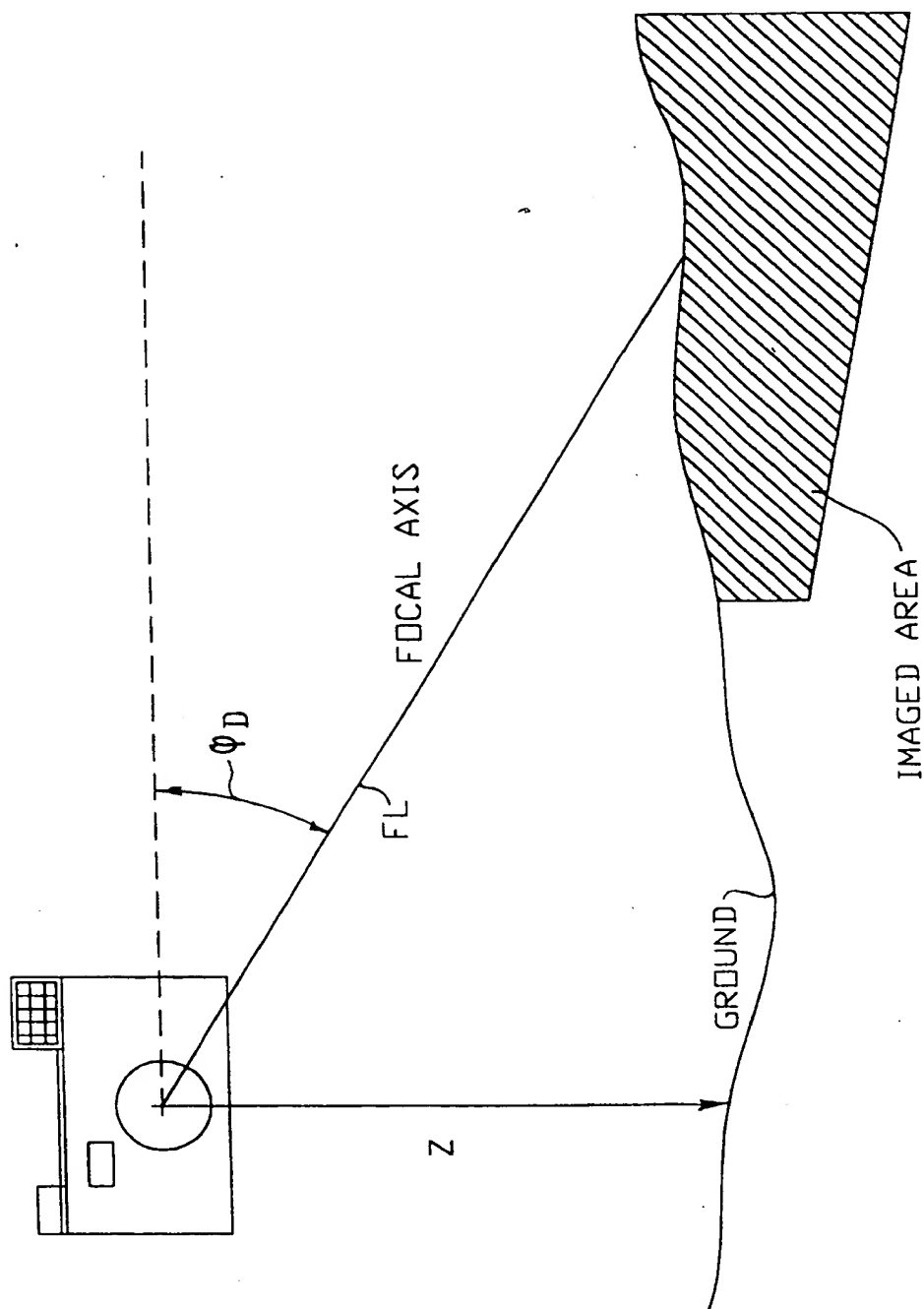
2/7

FIG. 2

3/7

FIG. 3

4 / 7

FIG. 4(a)

5/7

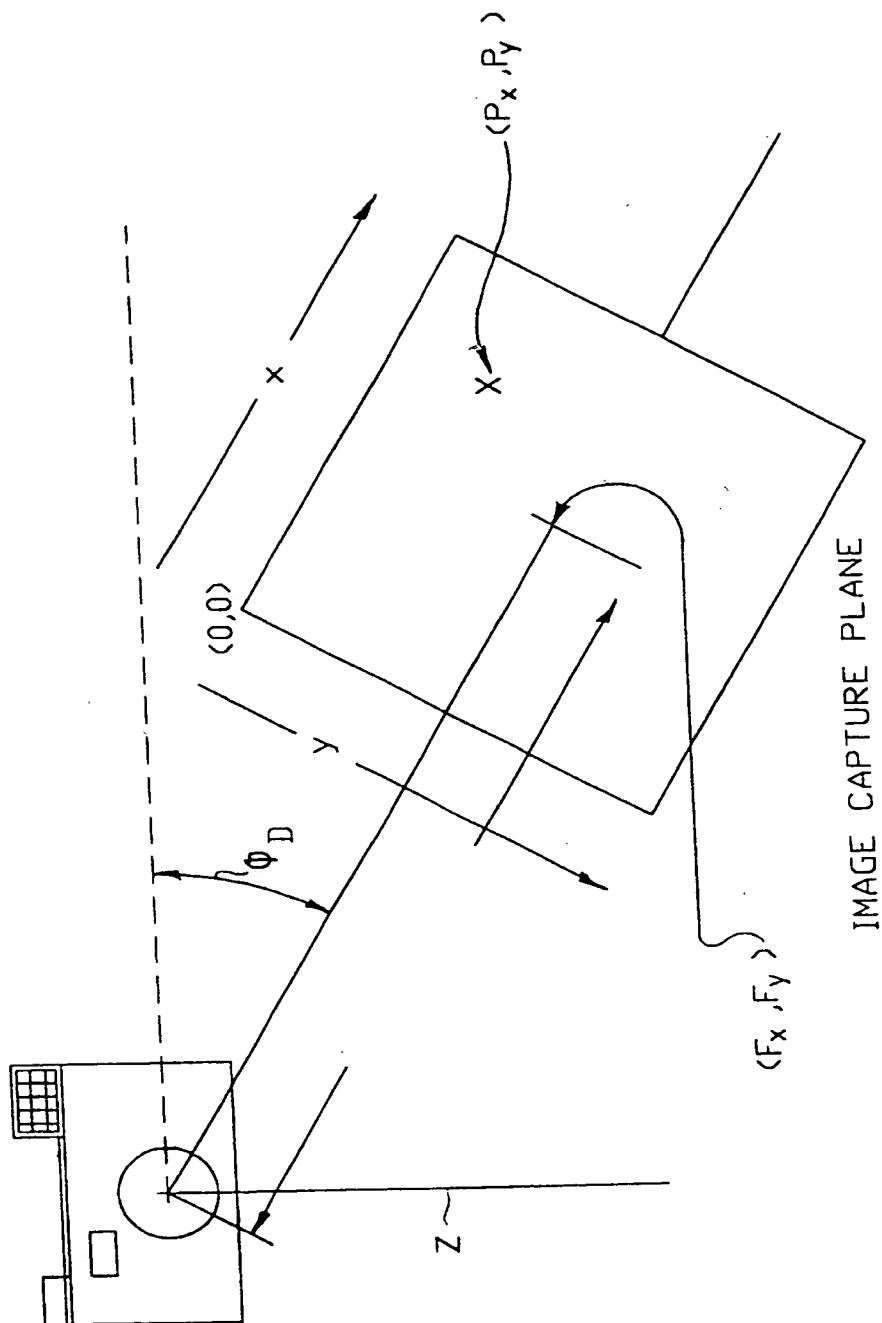


FIG. 4(b)

6/7

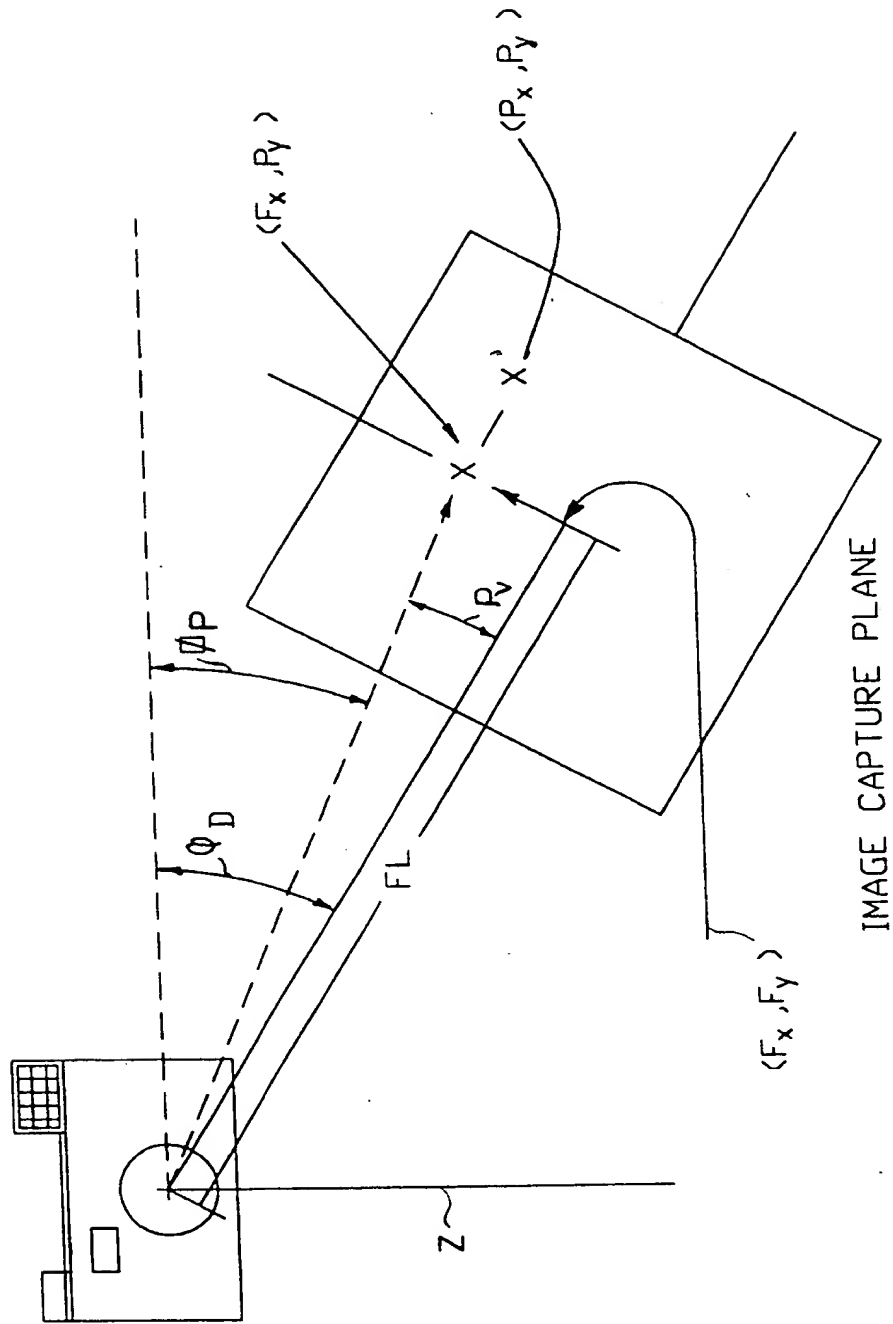


FIG. 4(c)

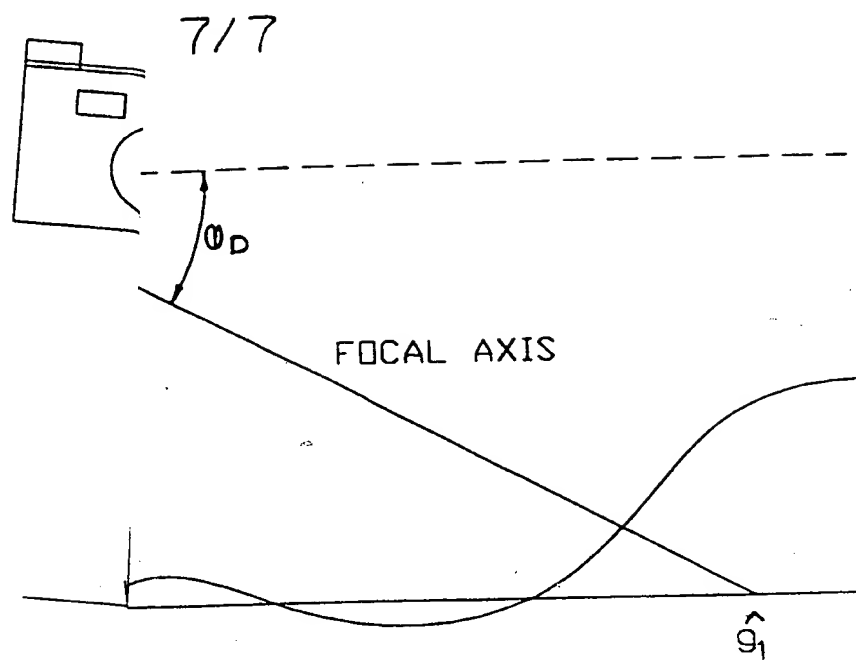


FIG. 4

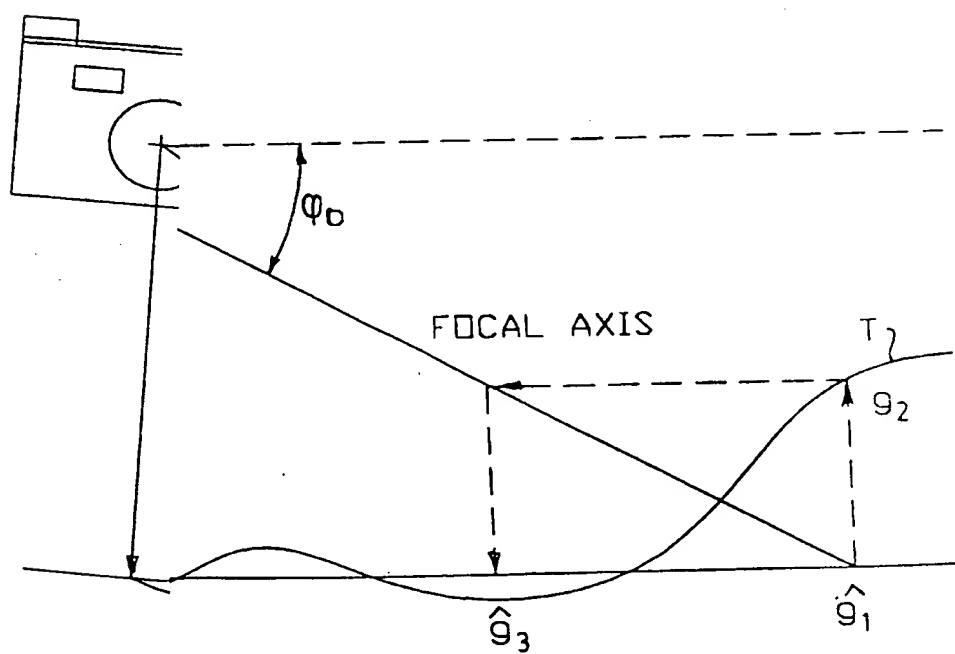


FIG. 5

## INTERNATIONAL SEARCH REPORT

International application No.  
PCT/US98/20809

## A. CLASSIFICATION OF SUBJECT MATTER

IPC(S) : Please See Extra Sheet.

US CL : 348/143,144,145,148, 373; 354/106; 364/420

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 348/143,144,145,148, 373; 354/106; 364/420

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched  
NONEElectronic data base consulted during the international search (name of data base and, where practicable, search terms used)  
NONE

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|-----------|--|-----------------------|
| X         | US, A, 5,467,271 A (ABEL et al.) 14 November 1995, col. 3-30 and Figs. 1-8         | 10-21, 22-38          |
| Y         | US, A, 5,467,271 A (ABEL et al.) 14 November 1995, col. 3-30 and Figs. 1-8         | 1-9, 22-38            |
| Y         | US, A, 5,508,736 A (COOPER) 16 April 1996, col. 3-6 and Fig. 1                     | 1-9, 22-38            |
| A         | US, A, 5,506,644 A (SUZUKI et al.) 09 April 1996, Figs. 3 and 9                    | None                  |

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

|   |  |
|---|--|
| * Special categories of cited documents:  | *T* later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention  |
| *A* document defining the general state of the art which is not considered to be of particular relevance  | *X* document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone   |
| *E* earlier document published on or after the international filing date  | *Y* document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art |
| *L* document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) | *A* document member of the same patent family  |
| *O* document referring to an oral disclosure, use, exhibition or other means  |  |
| *P* document published prior to the international filing date but later than the priority date claimed  |  |

Date of the actual completion of the international search

19 NOVEMBER 1998

Date of mailing of the international search report

28 JAN 1999

Name and mailing address of the ISA/US  
Commissioner of Patents and Trademarks  
Box PCT  
Washington, D.C. 20231

Facsimile No. (703) 305-3230

Authorized officer

VINCENT F. BOCCIO

Telephone No. 703-306-3022

Joni Hill

**INTERNATIONAL SEARCH REPORT**

International application No.  
PCT/US98/20809

**A. CLASSIFICATION OF SUBJECT MATTER:**

IPC (5):

H04N 7/18, 9/47, 5/225; G03B 17/24; G01V 1/00; G01W 1/10; G06F 17/00; G06G 7/48